Measuring the cosmological parameters with the $E_{p,i}$ – E_{iso} correlation of Gamma-Ray Bursts

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Abstract. **Recent studies have pointed out that the Hubble diagram for SNe-Ia may be affected by significant systematics. Therefore, an independent measurement of Ω_M and Ω_Λ based on a different experimental methodology is highly desirable. With this in mind, we have used the correlation between the spectral peak photon energy, $E_{p,i}$, and the isotropic-equivalent radiated energy, E_{iso}, of GRBs (a.k.a. "Amati relation") to measure the cosmological parameter Ω_M. By adopting a maximum likelihood approach, which allows us to correctly quantify the extrinsic (i.e. non-Poissonian) scatter of the correlation, we constrain (for a flat universe) Ω_M to 0.02-0.68 (90% confidence level), with a best fit value of Ω_M ~ 0.15, and exclude Ω_M = 1 at > 99.9% confidence level. If we release the assumption of a flat universe, we still find evidence for a low value of Ω_M (0.04-0.50 at 68% confidence level) and a weak dependence of the dispersion of the $E_{p,i}$ - E_{iso} correlation on Ω_Λ (with an upper limit of Ω_Λ ~ 1.15 at 90% confidence level). Our measurement makes no assumptions on the $E_{p,i}$ - E_{iso} correlation and it does not use other calibrators to set the "zero point" of the relation, therefore our treatment of the data is not affected by circularity. Simulations based on realistic extrapolations of ongoing (and future) GRB experiments show that the uncertainties on cosmological parameters can be significantly decreased and hopefully will allow us to get clues on the "dark energy" evolution.**

Main reference: Amati et al, 2008, MNRAS, in press (arXiv:0805.0377)

Gamma-Ray Bursts as cosmological probes

Gamma-ray Bursts (GRBs) are the brightest cosmological sources in the universe, with isotropic radiated energies up to more than 10^{54} erg cm^{-2} s^{-1}, released typically in a few tens of s, and a redshift distribution extending at least up to up to z ~ 6.3, much beyond, e.g., that of type Ia SNe (Figure 1). Thus, at least in principle, these sources may be interesting for cosmological studies, if one can use them to provide measurements of the cosmological parameters independently of other methods. However, GRBs are not standard candles, given that their luminosities span several orders of magnitude under the assumption of both isotropic and collimated emission. In the recent years, several attempts to use the GRBs as alternative rulers of the cosmological parameters, have been carried out on the basis of empirical correlations involving the spectral peak energy $E_{p,i}$ (Figure 2), the isotropic-equivalent radiated energy E_{iso} and a third observable (see Ghirlanda et al. 2006 for a review). These analyses have provided useful constraints on Ω_M and Ω_Λ. However, the use of these correlations for cosmology is controversial. For example, because of the lack of low redshift GRBs they cannot be directly calibrated. On the other hand, the calibration of a spectrum-energy correlation using SNe-Ia (e.g., Kodama et al. 2008, Liang et al. 2008) may suffer from circularity. In addition, recent analyses based on updated samples of GRBs showed that the dispersion of three parameters correlations could be significantly larger than thought before (Campana et al. 2007, Ghirlanda et al. 2007, Rossi et al. 2008). Thus, we investigated the possibility of constraining the cosmological parameters from the simple and most firm correlation between $E_{p,i}$ and E_{iso}. Although it was the first "spectrum-energy" correlation discovered for GRBs, the $E_{p,i}$ – E_{iso} correlation was never used before for cosmology purposes, because of its significant "extrinsic" scatter (i.e., a scatter in excess to the "intrinsic" Poissonian fluctuations of the data). However, it has the strong advantages of being based only on two observables, thus allowing the use of a much higher (a factor of ~4) number of events, together with a reduction of systematics.

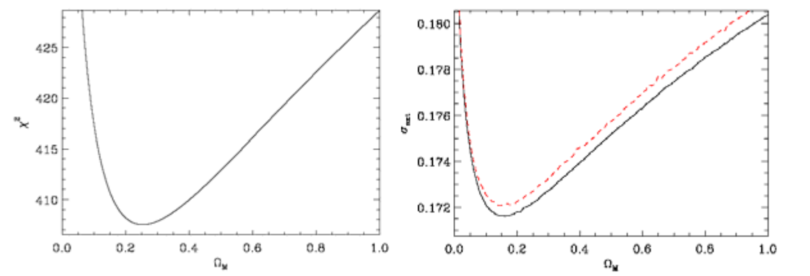

Figure 3: *Dispersion of the $E_{p,i}$ – E_{iso} correlation as a function of Ω_M in the assumption of a flat Universe. Left: χ^2 obtained by fitting with a simple power-law with the χ^2 technique. Right: extrinsic dispersion, σ_{ext}, quantified with our maximum likelihood method (see Amati et al. 2008 for details).*

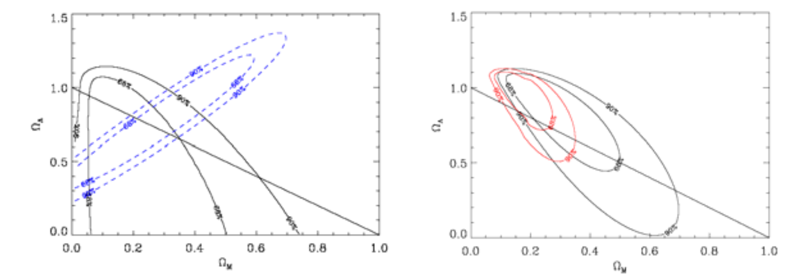

Figure 4: *Contours in the Ω_M - Ω_Λ plane obtained with the present sample of 70 GRBs (left; the blue contour was obtained by applying our method to the SN-Ia sample of Astier et al. 2006) and a simulated sample of 150 GRBs as expected in next future (left; the red contour was obtained by fixing the slope of the correlation to 0.5, as predicted by some GRB emission models).*

Results summary and future perspectives

Under the assumption of a flat universe, both the –log(likelihood) and the extrinsic scatter σ_{ext} show a parabolic shape with a minimum around Ω_M ~ 0.15 (Figure 3, right). The analysis of the probabiity density function (pdf) allows us to constrain Ω_M to 0.04-0.40 and 0.02-0.68 at 68% and 90% c.l., respectively. An Ω_M value of 1 can be exluded at ~99.9% c.l. If we release the flat universe hypothesis and let Ω_M and Ω_Λ vary independently we still find evidence for an universe with a low value of Ω_M (0.04-0.50 at 68% c.l.). Only an upper limit of ~1.05 can be set to Ω_Λ. We emphasize that our study does not make assumptions on the $E_{p,i}$ - E_{iso} correlation or make use of independent calibrators to set the "zero point" of the relation, therefore our approach does not suffer from circularity and provides independent evidence for the existence of a gravitationally repulsive energy component ("dark energy"), which accounts for a large fraction of the energy density of the Universe. The accuracy measurements provided by the GRB data is still not "competitive" with SNe-Ia. However, we have simulated the impact of ongoing/future GRB experiments (e.g., *Swift* + GLAST) on the future Ω_M and Ω_Λ measurements (Figure 4, right) and shown that the uncertainty range can be decreased by almost an order of magnitude with respect to the current GRB sample.

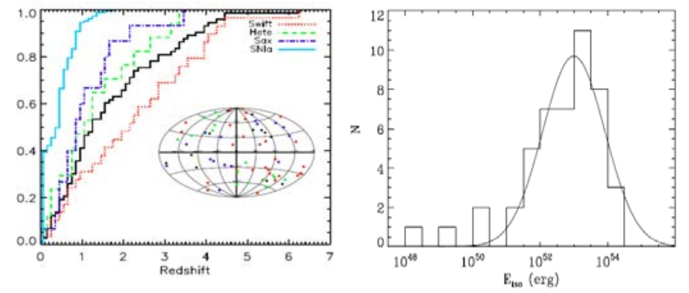

Figure 1: *Gamma Ray Bursts as the brightest cosmological sources: distributrion of redshift (left, from Ghirlanda et al., 2006) and of the isotropic-equivalent radiated energy (right, from Amati 2006) .*

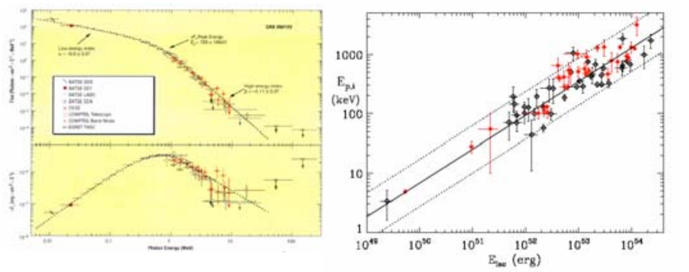

Figure 2: *The $E_{p,i}$ – Ei_{so} correlation of GRBs. Left: typical photon (top) and $\nu F\nu$ (bottom) spectrum of a GRB. Right: the $E_{p,i}$ - E_{iso} correlation for the 70 long GRBs used for this analysis (Amati et al. 2008); Swift GRBs are shown as red dots.*

Deriving cosmological parameters from Ep,i–Eiso correlation

The $E_{p,i}$ – E_{iso} correlation (Figure 2) was initially discovered on a small sample of *Beppo*SAX GRBs with known redshift (Amati et al. 2002) and confirmed afterwards by HETE-2, Konus-Wind and *Swift* observations (Amati 2006). It is one of the most firm and intriguing observational evidences in the GRB field, with relevant implications for the physics and geometry of the emission, the identification and understanding of sub-classes of GRBs, the GRB/SN connection. Despite the correlation is highly significant, the scatter of the data points around the best-fit power-law is significantly in excess of the Poissonian statistical fluctuations. We investigated whether this "extrinsic" dispersion is sensitive at varying the values of the cosmological parameters Ω_M and Ω_Λ in the computation of E_{iso}. Our analysis, based on a sample of 70 GRBs detected up to April 2008, was prompted by the evidence that, in the assumption of a flat universe, the χ^2 obtained by fitting the $E_{p,i}$ - E_{iso} correlation with a power-law varies with the value of Ω_M, with a minimum occurring at Ω_M ~ 0.25 (Figure 3, left). This result is in qualitative agreement with the one obtained, e.g., with SNe, but still difficult to quantify with the simple χ^2 technique because of the large χ^2 value. The correct way to account for the extrinsic scatter of the data is to use a maximum likelihood method like that discussed by D'Agostini et al. (2005) (see also Guidorzi et al. 2006). This method assumes a model consisting of a power-law with Gaussian dispersion (parameterised by its standard deviation σ_{ext}) and accounts for errors on both E_{iso} and $E_{p,i}$ coordinates. We emphasize that this method does not suffer from circularity, since we do not assume an $E_{p,i}$ - E_{iso} relation based on a particular choice of the cosmological parameters or calibrate it by using other cosmological probes. We assumed H_0 = 70 km s^{-1} Mpc^{-1}.

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